Dr Gavin Bell International Joint Project - 2010/R2 (inc CNRS and CSIR)

Title: Dr

First Name: Gavin

Surname: Bell

Preferred Name: Gavin

Address: Department of Physics
University of Warwick

Town: COVENTRY

Postcode: CV4 7AL

Country: United Kingdom

Nationality:
Nationality
British

Email Address: gavin.bell@physics.org

Telephone (home):

Telephone (mobile):

Telephone (work): 02476 523489

Fax: 02476 150897

Applicant Career Summary

Statement of qualifications and career:

Qualification	Date
Postgraduate Certificate in Academic and Professional Practice	15/06/2009
awarded C.R. Burch Prize by the British Vacuum Council	01/07/2005

Field of Specialisation: Epitaxial growth, surface science, magnetic and semiconducting materials

Publications:

1.
Band gap, electronic structure, and surface electron accumulation of cubic and rhombohedral In_2O_3
P.D.C. King, T.D. veal, F. Fuchs, C.Y. Wang, D.J. Payne, A. Bourlange, H. Zhang, G.R. Bell, V. Cimalla, O. Ambacher, R.G. Egdell, F. Bechstedt and C.F. McConville
Physical Review B (2009), vol. 79, article no. 205211

2.
Stoichiometry, contamination and microstructure of MnSb(0001) surfaces
S.A. Hatfield, J.D. Aldous and G.R. Bell,
Applied Surface Science (2009), vol. 255, p. 3567

3.
Organopalladium catalyst on S-terminated GaAs(001)-(2×6) surface
T. Konishi, T. Toujyou, T. Ishikawa, G.R. Bell and S. Tsukamoto,
Journal of Vacuum Science and Technology B (2009), vol. 27, p. 2206

4.
Mapping the surface reconstructions of MnSb(0001) and (1-101)
S.A. Hatfield and G.R. Bell,
Surface Science (2007), vol. 601, p. 5368

5.
Atomistic insights for InAs quantum dot formation on GaAs(001) using STM within a MBE growth chamber
S. Tsukamoto, T. Honma, G.R. Bell, A. Ishii, Y. Arakawa and N. Koguchi,
Small (2006), vol. 2, p. 386

Subject: Subject Group 02: Astronomy and physics, theoretical physics, and applied physics / Condensed matter (including softmatter, liquids and nano-materials)

Present Research: My present work mainly involves the growth of transition metal pnictides (TMPs), both as thin films on semiconductor substrates by molecular beam epitaxy (MBE) and as bulk single crystals and polycrystals. TMPs of particular interest are Mn, Cr and Ni antimonides and arsenides, and the ternary compounds NiMnSb and NiCrSb. I use surface science techniques to understand the growth and structure of the MBE thin films, including quantitative structural measurements on reconstructed TMP surfaces. These techniques include scanning tunnelling microscopy (STM), low energy electron diffraction (LEED), medium energy ion scattering (MEIS), X-ray photoemission spectroscopy (XPS) and density functional theory (DFT). I collaborate on magnetic measurements of TMPs using X-ray magnetic circular dichroism (XMCD) where we have recently been studying all-epitaxial ferromagnet/paramagnet/antiferromagnet layered TMP systems.

Present Position: Associate Professor

Present Employer: University of Warwick

Present Department: Department of Physics

Present Position Start Date: 05/10/2009

PhD Awarded Date: 01/03/1997

Current Funding Description: Royal Society research grant for developing LEED I-V studies of Heusler alloy surfaces - £7400
EPSRC overseas travel grant (for synchrotron radiation work at NSLS, USA) - £37500
Nuffield Foundation (undergraduate research project) - £1440

Previous Support Description: University Research Fellowship - from 2002, ended Oct. 2009
2 summer studentships

Co-Applicant Personal Details

Title: Professor

First Name: Shiro

Surname: Tsukamoto

Preferred Name: Shiro

Address Line 1: Material Engineering Lab

Address Line 2: Anan National College of Technology

Address Line 3: 265 Aoki, Minobayashi

Address Line 4:

Address Line 5:

Town: Anan

Postcode: 774-0017

Country: Japan

Nationality:

Nationality
Japanese

Email Address: tsukamot@anan-nct.ac.jp

Telephone (home):

Telephone (mobile):

Telephone (work): +81 884 23 7253

Fax: +81 884 23 7253

Co-Applicant Career Summary

Statement of qualifications and career:

Qualification	Date
appointed as full professor in Anan NCT	01/04/2007
appointed associate professor University of Tokyo	01/01/2003

Field of Specialisation: Semiconductor epitaxy, scanning tunneling microscopy

Publications:

1.
Akira Ishii, Hiroki Asano, Mami Yokoyama, Shiro Tsukamoto, Satoshi Shuto, and Mitsuhiro Arisawa
"Structure determination of Pd-catalyst supported on S-terminated GaAs(001) using DFT calculation"
Physica Status Solidi (c), vol.7, Issue 2, (2010), pp.359-361.

2.
N.Hoshiya, N.Isomura, M.Shimoda, H.Yoshikawa, Y.Yamashita, K.Iizuka, S.Tsukamoto, S.Shuto, and M.Arisawa
"Development of recyclable and low-leaching palladium catalyst supported on sulfur-modified gallium arsenide (001) plate for use in Suzuki-Miyaura coupling"
ChemCatChem, vol.1, (2009), pp.279-285.

3.
D.Guimard, Y.Arakawa, M.Ishida, S.Tsukamoto, M.Nishioka, Y.Nakata, H.Sudo, T.Yamamoto, and M.Sugawara
"Ground state lasing at 1.34 m from InAs/GaAs quantum dots grown by antimony-mediated metal organic chemical vapor deposition"
Applied Physics Letters, vol.90, Issue 24, (2007), 241110.

4.
S.Nagahara, M.Shimoda, S.Tsukamoto, and Y.Arakawa
"Enhancement of room temperature photoluminescence from InAs quantum dots by irradiating Mn"
Japanese Journal of Applied Physics Part 2 - Letters & Express Letters, vol.46, Issue 33-35, (2007), pp.L801-L803.

5.
Shiro Tsukamoto, Tsuyoshi Honma, Gavin R. Bell, Akira Ishii, and Yasuhiko Arakawa
"Atomistic insights for InAs quantum dot formation on GaAs(001) using STM within MBE growth chamber",
Small, vol.2, Issue 3 (2006) , pp.386-389.

Subject: Subject Group 02: Astronomy and physics, theoretical physics, and applied physics / Semi-conductors

Present Research: "Green" organopalladium catalysts
A completely novel function of semiconductors is successfully developed for organic synthesis, in which Pd supported on the surface of S-terminated GaN (0001) and GaAs(001) serves as a unique green chemical catalyst. It efficiently catalyzes the Heck reaction with simple manipulations and its high catalytic activity is retained for many repeat reactions.

STMBE (Scanning tunneling microscope / molecular beam epitaxy)
High density arrays of quantum dots (QDs) can easily be grown by 'self-assembly' for advanced semiconductor quantum devices. However, the precise mechanism of self-assembly is not fully understood. STM is a good technique to observe the surface in atomic level but it dislikes vibrations, temperature gradients and material depositions. We have overcome these challenges to observe STM during MBE growth inside MBE chamber. Many III-V surface structures/dynamics are analyzed centering on the observation of the QD self-assembly.

Present Position: Professor

Present Employer: Anan National College of Technology

Present Department: Center for Collaborative Research

Present Position Start Date: 01/04/2007

PhD Awarded Date: 31/03/1993

Previous Support Description: NA

Proposal

Subject: Subject Group 02: Astronomy and physics, theoretical physics, and applied physics / Semi-conductors

Project Title: Extreme epitaxy 'as it happens': STMBE of magnetic pnictides on GaAs

Research Aims: We will examine transition metal pnictide (TMP) ultra-thin films on GaAs using a unique scanning tunnelling molecular beam epitaxy (STMBE) instrument capable of STM imaging during MBE growth and annealing under pnictogen flux. Specific experiments are outlined below with a brief comment which is expanded on in the next section. The overall goal is to understand the interplay between surface structure, epitaxy conditions and resulting magneto-structural properties.

1. MnSb(0001) / GaAs(111) - compare STMBE with existing STM-MBE data
2. GaAs(111) / MnSb(0001) - reverse interface formation on reconstructed MnSb
3. MnAs(1-10m) / GaAs(001) growth - nanowire self-assembly (m = 0,1,2)
4. MnAs(1-10m) / GaAs(001) annealing - phase coexistence and vicinality

Research proposal: Transition metal pnictides such as MnAs and CrSb are very promising materials for combination with conventional III-V semiconductors in spintronic and nano-magnetic devices, and possibly even magnetocaloric cooling devices. We term the TMP / III-V system 'extreme' heteroepitaxy due to the mismatch of both crystal structures and in-plane lattice parameters, and although high quality interfaces can be grown the details of the epitaxy have strong effects on the magneto-structural properties of the MnAs layer (reviewed in [1]). The case of MnAs is further complicated by a hexagonal / orthorhomic bulk phase transition at around 40 C which interacts with epitaxial strain to produce rich behaviour.

Two ultra-high vacuum (UHV) systems will be used. The STM-MBE machine in Warwick is capable of growing antimonides, including fully relaxed MnSb films with protective Sb capping for transfer to Japan [2], and employs quenched-mode STM imaging capability. The STMBE system in Anan allows growth of arsenides and (ultra-thin layer) antimonides, and provides true in situ imaging during MBE [3]. The UHV measurements will be supported in Warwick by ex situ atomic force and magnetic force microscopy (MFM).

E1. MnSb(0001) / GaAs(111)
We have extensive experience in growing this interface [2] and will use the system to compare STMBE with STM-MBE data. We will focus on the earliest stages of film growth and examine surface dynamics and the change of reconstruction of GaAs as the film develops. The STMBE will give a unique insight into the process by which the reconstructed surface becomes a heterointerface; the interface atomic layer ordering is key to the spin transport properties of TMP / III-V interfaces [4].

E2. GaAs(111) / MnSb(0001)
While the growth of all-epitaxial III-V/TMP/III-V layers is well established, no detailed work has been performed on the growth of GaAs on TMP. We will examine interface formation with the same aims as above. We can also replace the MnSb films with NiSb and CrSb to test the effects of epitaxial strain on the GaAs overgrowth.

E3. MnAs(1-10m) / GaAs(001) growth
It is possible to grow nanowire arrays of MnAs on GaAs(001) [5]. We will observe their formation using STMBE to understand better the surface dynamics [3] and the possibility of improved control by epitaxy conditons (especially As/Mn flux ratio) and vicinal substrate miscut (changing both step density and step direction on the highly anisotropic GaAs 2x4 surface).

E4. MnAs(1-10m) / GaAs(001) annealing
We will try to image the formation of structural "stripe" domains on epitaxial MnAs films near the bulk transition temperature, during in situ low T annealing [1]. Recently the role of vicinality has been investigated [6] and we will use different miscuts of GaAs(001) to observe its effects on the phase change.

Technically, this work is within the proven limits of the STMBE system to provide dynamic, stable imaging during growth and annealing [3]. We will use ultra-low TMP deposition rates, minimising radiant heat to reduce drift. Stabilised substrate temperatures in the range 0 - 400 C are compatible with stable STMBE operation at atomic resolution. Supporting STM-MBE and MFM measurements will be made in Warwick, including T-dependent MFM around 40 C on MnAs films.

[1] Unforeseen properties of MnAs epilayers grown on GaAs semiconductor, Physica B 404 (2009) 2684
[2] Stoichiometry, contamination and microstructure of MnSb(0001) surfaces, Appl. Surf. Sci. 255 (2009) 3567
[3] Atomistic insights for InAs quantum dot formation on GaAs(001) using STM within a MBE growth chamber, Small 2 (2006) 386
[4] The continuing drama of the half-metal/semiconductor interface, J. Phys. D. 39 (2006) 793
[5] Self-assembly and magnetic properties of MnAs nanowires on GaAs(001) substrate, J. Appl. Phys. 107 (2010) 063909
[6] Surface structure and magnetic properties of MnAs epilayers grown on vicinal GaAs(001) substrates, J. Appl. Phys. 106 (2009) 114319

Scientific Abstract:

Transition metal pnictide (TMP) ultra-thin epitaxial films on III-V semiconductors have strong potential in several applications, principally spintronic devices but also possibly for "on-chip" magteocaloric refrigeration. They also show complex molecular beam epitaxial (MBE) behaviour due to the interplay of crystal structure mismatch and strain as well as bulk crystal structure changes in some cases. In this project we will exploit a unique STMBE system - capable of atomic resolution scanning tunnelling microscopy imaging of surfaces during MBE growth - to understand better the 'extreme' heteroepitaxy of several carefully chosen combinations of TMPs and GaAs. In particular we will examine growth modes, nanowire formation and reconstruction changes, trying to develop better control over each aspect of the heteropeitaxy. We plan to leverage broader collaborations from this work, involving both technique development for combined STM-MBE studies and exploitation of the particular systems to be examined during the project.

Resources required:

Contributing staff member in Anan NCT: Dr. M. Hirayama (Assistant Professor). He has published recent first-principles calculations on Mn nanowires on GaAs (110) [JVST B 27 (2009) 2062] and will be able to provide theoretical support for E3. This will be invaluable in maximising research impact (e.g. by property prediction for observed structures) and developing broader future collaborations to exploit understanding developed in this project.

We plan three UK -> Japan visits and two Japan -> UK visits over the 2 years. In Japan, we will focus on the core STMBE experiments E1-E4. In the UK we will produce the Sb-capped MnSb films for E2, and exploit the STM-MBE system for E1 (STM-MBE under STMBE-like growth conditions) as well as performing supporting AFM / MFM measurements for E3 and E4.

Participants:

Contributing PhD student in Warwick: Christopher Burrows
Second year, working on MBE growth and structure of TMPs, skilled in STM and AFM.
Will lead AFM, MFM and MnSb/Sb film growth in Warwick.
STMBE in Anan will complement present work (one visit to Japan proposed).

Contributing research students in Japan: T. Teraoka, N. Isomura and N. Kakuda
All are skilled in operating the STMBE system. STMBE experiments are typically very lengthy and ideally need three people in the lab, so all will contribute to the core STMBE work.
One visit to Warwick for each of Kakuda & Isomura is proposed to work on MBE, AFM, MFM and STM.

Previous contact:

Dr. Bell and Professor Tsukamoto have collaborated regularly since 1999 (with past support from EPSRC and Dr. Bell's Royal Society URF in the UK, and from NIMS in Japan) and co-authored 7 papers. They recently worked closely to organise the SemicoNano2009 international workshop in Anan, Japan, an invitation-only focused meeting with ~ 60 participants from Europe, the US and Asia.
Please see http://www.anan-nct.ac.jp/material/semiconnano/ for details of this meeting.

Comply with Policy on use of Animals:

Not applicable

Benefits to individuals/institutions:

Dr. Bell and Prof. Tsukamoto will be able to continue a long-standing and fruitful collaboration. The student exchange is very valuable, and Dr. M. Hirayama (recently appointed Asst. Prof. in Anan) is keen to broaden his research portfolio. C. Burrows (Warwick PhD) is very interested in pursuing postdoctoral research in Japan. This work would form a strong part of his PhD thesis. The project will lead to future research proposals both between the two groups and more broadly (e.g. see below).

Benefits to UK:

The STMBE system in Prof. Tsukamoto's laboratory is a unique instrument worldwide and access to this system is an obvious benefit. The closest equivalent in the UK is the MBSTM machine at the III-V Centre in Sheffield. Dr. F. Bastiman is working there on related materials and we forsee a potential larger collaboration based around the three "flavours" of STMBE, MBSTM and STM-MBE. The work will also benefit the broader UK research effort in spintronics.

Benefits to Overseas Country:

The reverse heteroepitaxy experiments require well characterised surfaces which will be provided by the Warwick group. The visiting students will benefit greatly from the experience of working in an English-speaking laboratory as well as being able to learn new techniques such as MFM. There is considerable interest and expertise in TMP / III-V epitaxy among other groups in Japan and it is likely that new collaborations will arise, also exploiting the major new microscopy facilities in Warwick.

Lay Report:

Our ability to manipulate tiny electric currents and charges has changed the world. For example, the transistors on a typical silicon chip work by pushing electrons around or storing them using their small negative charge. This is done using voltages, which produce electric fields. But electrons also have a property called spin, which is sensitive to magnetic as well as electric fields. This is a quantum-mechanical property but in an external magnetic field, the spin tends to align either parallel or opposite to the field - towards the north or south pole. This "spin up" or "spin down" configuration is a beautiful analogue to the digital "0" or "1" bit of information. Processing and storing information using electron spins is a growing field of technology called "spintronics". It could be possible to develop ultra-low-power spintronic transistors which operate at high speed, for energy efficient computer processing (computer server farms, for example running financial, search and streaming services over the web, are enormous electricity consumers). It may be possible to combine processing and memory by building magnetic transistors which remember their magnetic state when the power is switched off. It may even be possible to use spins to perform quantum computation, i.e. as qubits rather than classical bits.

Just as the technology of electronics depended on developing many semiconductor materials (and suitable insulators) spintronics will depend on understanding the behaviour of spins in real materials. The best source of spins is by using a magnetic material, in which there is naturally an imbalance between the numbers of spin up and spin down electrons. However, we want to manipulate the spin carriers in a material such as silicon or another non-magnetic semiconductor, since the highly developed technology of these materials allows us to make the best devices. We are interested in an exciting class of materials, the transition metal pnictides (TMPs), because they are compatible with the production of conventional semiconductors as well as having excellent magnetic properties.

In fact, the best interfaces between the two types of materials arise when both are crystals, i.e. have a highly regular atomic structure. The layering of one crystal on another is called "heteroepitaxy" and can be controlled to an accuracy of single atomic layers. We will use a unique machine capable of imaging the process of heteroepitaxy at the atomic scale during heteroepitaxy; it combines scanning tunnelling microscopy (STM) with molecular beam epitaxy (MBE) and is hence known as STMBE. Our aim is to understand how TMPs grow on ordinary semiconductors. We call this "extreme epitaxy" because the TMP crystal structures and atomic spacings are different from those of the semiconductor. Rich behaviour arises as the TMP atoms try to arrange themselves into their preferred structure while still being influenced by the underlying semiconductor. We want to control the growth process so that magnetic nano-structures arise spontaneously. If we can understand and control extreme heteroepitaxy of magnetic materials on semiconductors, this combination of materials could be used for the next generation of spintronics.

Financial Details

Financial Details:

Year	Payment type	Justification	Amount Requested
Year 1	Travel International	Bell (UK): to Anan (£850); Burrows (UK): to Anan (£850); Isomura (Japan): to Warwick (£950)	2,650.00
Year 1	Subsistence	Bell (UK): 20 days in Anan (£1000); Burrows (UK): 30 days in Anan (£1500); Isomura (Japan): 25 days in Warwick (£1150)	3,650.00
Year 1	Research Costs	AFM/MFM probes (£200); Omicron STM tips (£200); MBE & UHV consumables: GaAs vicinal / just wafers (£400), Cu gaskets (£50), liquid nitrogen (£50), two Mn cell reloads (£100)	1,000.00
Year 2	Travel International	Bell (UK): to Anan (£850); Kakuda (Japan): to Warwick (£950)	1,800.00
Year 2	Subsistence	Bell (UK): 15 days in Anan (£800); Kakuda (Japan): 25 days in Warwick (£1100)	1,900.00
Year 2	Research Costs	AFM/MFM probes (£200); Omicron STM tips (£200); MBE & UHV consumables: GaAs vicinal wafers (£400), Cu gaskets (£50), liquid nitrogen (£50), Sb source reloads (£100)	1,000.00
Total			12,000.00

Sum requested from the Royal Society: 12000.00

Duration (Years): 2

Pending Proposed Applications: NA

Other Funding Sources: NA